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Sorghum for Grain: Production Strategies in the Rolling Plains

The Texas Agricultural Experiment Station, Neville P. Clarke, Director, The Texas A&M University System, College Station, Texas

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SUMMARY

With proper management, dryland production of grain sorghum seems feasible and desirable on the Rolling Plains of Texas. Profitable production of dryland sorghum requires that growers plant a high-yielding, medium-maturing hybrid in June. Management strategies of grain sorghum include furrow diking and, if needed, deep tillage or subsoiling. Runoff often can be prevented and additional water captured by furrow diking to produce an average of 3,000 pounds of grain per acre. Plant residues play an important role in soil productivity and crop production.

KEYWORDS: Grain sorghum/furrow diking/subsoiling/plant residues/fine sandy loam/clay loam/yield/Central Rolling Red Plains

Sorghum for Grain: Production Strategies in the Rolling Plains

C. J. Gerard, P. Sexton, L. E. Clark, and E. C. Gilmore, Jr.*

INTRODUCTION

The two most important cash crops in the Rolling Plains are cotton and wheat. Grain sorghum ranks a poor third behind wheat, which provides only about half the cash receipts produced by cotton. Water is the dominant factor for yields in the Rolling Plains (5), and under present cultural methods water frequently is not sufficient to produce economical yields of dryland sorghum in the Rolling Plains.

Production systems are needed in the Rolling Plains which return a significant amount of residue to the soil. Because of poor structural stability related to low organic matter, soils in the Rolling Plains are subject to compaction and runoff and have low permeability to rainwater. High temperatures common in the Rolling Plains contribute to rapid decomposition of plant residues and low soil organic matter.

In the High Plains of Texas, Bilbro and Hudspeth (1), Hudspeth (6), and Lyle and Dixon (8) have used basin tillage or diking to reduce runoff and increase crop yields. In 1977, Bilbro and Hudspeth (1) reported that furrow diking increased cotton yields by 10 to 15 percent. Hudspeth (6) reported dryland cotton yields from 1975-1978 were increased from 30 to almost 70 pounds per acre (lb/A) by furrow diking. Furrow diking appears to be a possible way of reducing runoff and erosion while increasing the yields of dryland grain sorghum in the Rolling Plains.

Stephens and Quinby (13) have been credited with development of hybrid grain sorghum at the Chillicothe Research Station in the Rolling Plains. Increased yields of hybrid sorghum caused it to become a profitable crop and by 1960 it occupied 95 percent of the acreage of sorghum for grain (10). Sorghum produces large amounts of residue which should be beneficial to soils in the Rolling Plains; however, in 1979 and 1980 only 30,000 to 40,000 acres of sorghum were harvested in the northern Low Plains (14, 15). The Rolling Plains is often plagued by drought periods; sorghum, being a determinant plant, is susceptible to drought during critical stages of its growth.

These studies were conducted to determine if cultural practices to conserve water could be used effectively to increase yields of grain sorghum in the Rolling Plains. The effects of subsoiling and furrow diking on sorghum yields, and incorporating of plant residues on soil conditions, were studied.

METHODS AND MATERIALS

Subsoiling and Diking

The influence of subsoiling and diking on yields of sorghum was evaluated in 1979, 1980, and 1981. This experiment was conducted on an Abilene clay loam soil (properties in Table 1) and was a randomized block design with three replications. All treatments, described in Table 2, were 12 rows wide and about 200 feet (ft) in length. The locations of all treatments were the same throughout the time of the experiment. The slope of the field down the rows ranged from 0.1 percent on the lower half to 0.4 percent on the upper half. The lower 50 ft of the field had a low place which tended during significant rainfall to accumulate water from the upper side of the field.

Land on which the experiment was installed was planted to cotton in 1978. In 1979 land preparation consisted of bedding and re-bedding prior to or during installation of the subsoiling and diking treatments. Treatments 1 and 2, the check treatments (Table 2), had no other tillage operations until beds were cultivated with a rolling cultivator immediately prior to planting in 1979. In 1980 treatment 2 was changed to evaluate diking interval, and in 1981 it was changed to evaluate diking alternate middles (half diked).

Subsoiling treatments were installed March 8, 1979, during the bedding and re-bedding operation. Treatments 3 and 5 were subsoiled on 20-inch intervals parallel with rows. After the first bedding operation furrows were subsoiled to a depth of 16 inches; re-bedding was accomplished and furrows were again subsoiled to the same depth. Dikes 6 to 8 inches in height were installed by hand 50 ft apart in all furrows of treatments 4 and 5 on March 9.

All beds were cultivated, and Pioneer hybrid 8501 was planted at a rate of about 3 seed per foot (seed/ft) of row June 21. Propazine was applied broadcast on June 22 at a rate of 1.2 lb/A. Dikes which were broken for planting were reinstalled July 24.

Plant height measurements were taken late August after anthesis. Grain yield was obtained by harvesting three center rows with a combine on October 12. Four samples were taken at 50-ft intervals down the row to correspond with diking intervals and to measure the effect of slope on yield.

*Respectively, professor, technician, associate professor, and professor and resident director, Texas Agricultural Experiment Station, Vernon, Texas 76384.

TABLE 1. THE pH, PERCENT ORGANIC MATTER, AND PARTICLE SIZE DISTRIBUTION OF ABILENE CLAY LOAM AND MILES FINE SANDY LOAM AT DIFFERENT SOIL DEPTHS

	Soils									
	Abilene Clay Loam					Miles Fine Sandy Loam				
Soil depth	pH	organic matter*	sand	silt	clay	pH	organic matter	sand	silt	clay
Inches			%					%		
0-6	6.9	1.00	45	26	29	5.8	0.40	76	13	11
6-12	6.9	1.05	45	28	27	6.4	0.33	73	13	14
12-24	6.9	0.91	45	25	30	6.7	0.38	58	15	27

*Standard error = ± 0.05

TABLE 2. DESCRIPTION OF TILLAGE TREATMENTS IN 1979, 1980, AND 1981

Treatment No. [a]	Description
	1979
1. Check	No treatment
2. Check	No treatment
3. Subsoiled	Land was subsoiled 16 inches deep below beds and furrows
4. Diked	Rows were diked 50 ft apart
5. Subsoiled and Diked	Rows were diked and subsoiled as described under Treatments 3 and 4
	1980
1. Check	No treatment
2. Diked	Rows were diked 8 ft apart
3. Subsoiled	Land was subsoiled 16 inches deep below beds and rows in 1979
4. Diked	Rows were diked 4 ft apart
5. Subsoiled and Diked	Rows were diked and subsoiled as described under Treatments 3 and 4
	1981
1. Check	No treatment
2. ½ Diked	Every other row was diked 6 ft apart
3. Subsoiled[b]	Subsoiled 16 inches deep below beds and rows in 1979
4. Diked	Rows were diked 6 ft apart
5. Subsoiled and Diked[b]	Rows were diked and subsoiled as described under Treatments 3 and 4

[a]Treatments were 12 rows wide and about 200 ft in length and replicated three times.

[b]The subsoiled plots were split in 1981. In 1981 six rows were subsoiled 14 inches deep in the furrow. The other six rows were not subsoiled in 1981.

In 1980, land preparation consisted of shredding sorghum stalks from the previous crop and discing with a tandem disc on April 7. Beds were re-established in their original location and dikes established April 8. Dikers manufactured in Lockney, Texas, were mounted behind lister sweeps and adjusted to establish dikes about 6 to 8 inches high on 4- or 8-ft intervals in the furrow. The tripping mechanism which determined intervals between dikes was a 3-ft-diameter wheel. Beds were plowed June 13 and Pioneer hybrid 8501 was planted June 18 at a rate of about 3 seed/ft of row. Propazine was applied broadcast June 18 at a rate of 1.2 lb/A. Sorghum was cultivated with a rolling cultivator July 9 and dikes were re-established in appropriate treatments July 18. Residual effects of subsoiling were evaluated in 1980 (Table 2). Because of low yields in 1980, sorghum was not harvested in 50-ft increments down the row as in 1979. Instead, three center rows 200 ft long were harvested for yield determination November 13.

Land preparation for the 1981 crop consisted of shredding stalks and moldboarding January 20 and 21. This was followed by tandem discing and land planing the area to make the slope more uniform and fill some low areas where water accumulated. Beds were re-established in their original location, and appropriate treatments were diked January 28. In treatment 2 (Table 2), alternate furrows were diked (half diked). All furrows in treatments 4 and 5 were diked; diking intervals for all treatments were about 6 ft. Subsoiling was accomplished for treatments 3 and 5 during the bedding operation. Half of each of the 12-row plots was subsoiled to a depth of about 14 inches; the other six rows were not subsoiled.

Weeds became a problem in the test area, so beds were cultivated for weed control, and Propazine was applied at a broadcast rate of 1.2 lb/A and incorporated with a rolling cultivator on April 13. Dikes were re-established in appropriate treatments the same day. Beds were cultivated and Pioneer hybrid 8501 was planted July 6 at a rate of about 3 seed/ft of row. Dikes were re-established in appropriate treatments on August 3 after satisfactory stand establishment. Yield determinations were made by combine harvesting three center rows on October 26. Three 60-ft increments were harvested down the slope for each treatment to evaluate effect of slope on yield.

In 1981, dikers were modified to trip by means of a hydraulic motor-driven mechanism described by Lyle and Dixon (8). This replaced the 3-ft diameter wheel used in 1980 and provided a more uniform diking interval. Removing the wheel also allowed shortening of the dikers by about 3 ft, which allowed easier handling of less weight.

Sorghum in these experiments was uniformly fertilized with 250 lb/A of 16-20-0 each year. Soil moisture at 1 to 4 feet at 6-inch increments was determined using neutron scattering technique. In 1979, moisture use was determined about 75 ft from the upper side of slope. In 1980 and 1981 moisture use by sorghum was measured on the upper, middle, and lower part of slope. Distance of access pipes with respect to slope for monitoring soil moisture were about 30, 90, and 150 ft down slope for upper, middle, and lower part of slope, respectively. Test weight and grain moisture were determined for combined grain samples each year, and grain yield was adjusted to 13 percent moisture. Yield data was subjected to analysis of variance. Regression analysis of yield and water use was used to determine the relationship of yield and total water use as well as yield and water use in inches per day for the 30- to 60-day period of growth (panicle development stage of plant growth).

Yield Potential for Sorghum in the Rolling Plains

Pan evaporation and dryland yield data at Chillicothe and Munday were used to determine the relationship between water deficit and grain yields for 1976 to 1981. The water deficit was defined as pan evaporation in inches from a Class A Weather Bureau pan minus the rainfall received. The relationship of water deficit and grain yields was used with water deficit data from 1914 to 1981 to estimate the probabilities of various levels of sorghum grain yield in the Rolling Plains. The necessary calculations used to make these estimates are given below.

Class A Weather Bureau pan evaporation data for Chillicothe have only been measured since 1976. However, evaporation from a 2-ft sunken pan was measured for the years 1914-1981. Estimates of water deficit from a Class A pan for the years 1914-1981 for months May through September were obtained from the regression of measurements of water deficits from a Class A pan and water deficit from a 2-ft sunken pan for the period 1976-1981. The equation for water deficits for months May through September from a Class A pan as a function of a 2-ft pan was $\hat{y} = 24.4 + 0.70X$ ($r = 0.96$) where $\hat{y}$ = water deficits from Class A pan in inches and X = evaporation from 2-ft pan in inches. The frequencies of years with water deficits of 30 to 35, 35 to 40, 45 to 50, and 55 to 60 inches from May through September were calculated. The dryland sorghum yield for each water deficit category was estimated from a regression of yield on water deficit described above. Rainfall, pan evaporation from Class A Weather Bureau pan, and temperature data for 1979-1981 are shown in Tables 3 and 4. The implications of these data for potential dryland grain sorghum production in the Rolling Plains are discussed in "Results."

Management Effects on Soil Properties

The effects of different cropping systems on selected chemical and physical properties of a Miles fine sandy loam soil were determined. The cropping systems compared include continuous sorghum, cotton, and wheat; a cotton-guar rotation; and a wheat-guar double crop system. This study was initiated in

TABLE 3. RAINFALL AND PAN EVAPORATION DATA FROM A CLASS A PAN FOR 1979-1981 AT CHILLICOTHE, TEXAS

	Rainfall			Evaporation		
Months	1979	1980	1981	1979	1980	1981
	Inches			Inches		
January	1.49	2.14	0.04	*	2.80	4.75
February	0.43	0.71	0.80	1.76	3.51	5.98
March	2.37	0.42	1.55	6.95	7.59	6.01
April	2.10	0.72	3.19	8.01	10.40	8.78
May	6.23	7.43	5.20	10.46	7.05	8.88
June	4.16	1.17	3.87	13.94	15.13	13.07
July	3.03	0.00	0.69	12.43	20.63	16.58
August	5.31	0.44	0.83	12.33	17.02	12.15
September	0.01	2.42	0.74	10.21	9.42	11.10
October	1.97	0.78	2.28	11.07	8.55	7.07
November	1.36	0.60	0.66	4.56	4.30	5.37
December	1.21	1.18	0.28	3.25	3.68	3.65
Total	29.67	18.01	20.13	94.97	110.08	103.39

*Pan remained frozen.

TABLE 4. TEMPERATURE DATA AT CHILLICOTHE FOR 1979, 1980, AND 1981

	Mean Minimum temperature			Mean Maximum temperature			Mean Mean temperature		
Months	1979	1980	1981	1979	1980	1981	1979	1980	1981
	°F			°F			°F		
January	20.5	29.4	30.6	39.7	51.5	56.7	30.1	40.4	43.6
February	25.3	28.8	33.2	38.6	57.5	60.7	38.6	43.1	46.9
March	39.3	36.5	43.2	67.3	67.1	67.2	53.3	51.8	55.2
April	47.2	44.6	54.7	73.8	78.6	81.1	60.5	61.6	67.9
May	54.5	56.7	59.9	83.4	84.5	84.6	68.9	70.6	72.3
June	64.2	71.5	69.0	92.4	100.0	94.9	78.3	85.8	82.0
July	70.2	76.4	75.1	96.6	105.5	100.2	83.4	91.0	87.6
August	67.5	74.8	70.2	93.4	100.7	95.3	80.4	87.7	82.7
September	61.6	68.1	65.1	90.5	90.0	92.1	76.0	79.0	78.6
October	52.9	51.1	55.2	84.4	79.6	75.6	68.6	65.4	60.7
November	34.7	39.9	41.4	61.7	64.6	68.1	48.2	52.3	54.8
December	31.4	34.6	33.7	55.7	60.1	58.6	43.5	47.3	46.2

1975 and is ongoing at the Chillicothe Research Station. Selected properties of the Miles soil at Chillicothe are reported in Table 1.

Bulk densities and organic matter determinations under different cropping systems were evaluated by taking cores of the 0-6, 6-12 and 12-24-inch soil depths with a Giddings sampler in December, 1980. The organic matter was determined according to the Walkley method (16). The saturated hydraulic conductivity (K_s) of the 0-3- and 9-12-inch soil depths under different cropping systems was evaluated by taking undisturbed soil cores with the Giddings sampler in December, 1980, June, 1981 and November, 1981. Polyvinyl chloride (PVC) cores were 3 inches in height and 4 inches in diameter. The cores were transferred to the laboratory and analyzed for K_s according to the method described by Klute (7).

Laboratory studies evaluated the roles of residue and antecedent moisture on K_s of Miles fine sandy loam and Abilene clay loam soil. Soil properties of Miles and Abilene soils used in these studies are reported in Table 1. For these evaluations sections of PVC pipe 6 inches in height and 4 inches in diameter were filled with surface Miles and Abilene soils to a depth of 3 inches. The soil was broken up and mixed to simulate a discing operation. The soil was divided into three equal samples. Sorghum residue equivalent to 5,000 and 10,000 lb/A was added to each of two samples. The third sample received no residue. The sorghum residue was ground to pass through a 20 mesh sieve (0.8 mm opening). The residue was added to the soil and thoroughly mixed. Three inches of these soils amounted to about 1.8 lb (800 grams) of oven dry soil per core.

Soils in cores with different amounts of residues were dried for 3, 6, and 9 days at 90 to 95° F. The antecedent volumetric moisture contents of the Miles soil after 3, 6, and 9 days averaged 6.9, 1.1, and 0.2 percent, respectively. Antecedent moisture refers to moisture content of cores after drying and prior to saturation in distilled water for evaluation of K_s. The antecedent volumetric moisture contents of the Abilene soil after 3, 6, and 9 days were 12.7, 5.4, and 1.7 percent, respectively. Each drying interval and residue treatment was replicated three times. The K_s of each treatment were determined, according to a method described by Klute (7), initially and after each interval of wetting and drying. The number of wetting and drying cycles for cores dried 3, 6, and 9 days were 11, 6, and 6, respectively. These studies suggest that the cores approached an equilibrium (K_s) value after four to six wetting and drying cycles. The equilibrium K_s of soil as functions of antecedent moisture and added residue are reported and discussed in "Results."

The effects of subsoiling on soil compaction and sorghum production were evaluated. Soil strength, an index of compaction, refers to resistance of the soil to penetration by a metal probe called a soil penetrometer. Resistance to penetration by a penetrometer varies with soil moisture and density and is expressed in atmospheres. The strength of the top 24 inches of a Miles soil when wet, at about field capacity, was determined using a recording penetrometer mounted on a Giddings soil sampler. The tapered steel rods used for strength measurements were about ½ and ¾ inches in diameter depending on the strength of the soil. The shafts of the rods were about ¼ inch smaller than the maximum diameter of these tapered rods. These rods were mounted in a load button of a 300-lb transducer. The millivolt (mv) output, which is a linear function of soil resistance to penetration at different soil depths, was continuously monitored with a mv recorder.

RESULTS

Subsoiling and Diking

Yields of sorghum grown under different tillage practices in 1979, 1980, and 1981 at Chillicothe are shown in Tables 5, 6, and 7, respectively. The overall averages for years 1979-1981 are represented in Table 8. During these years, yields of the check treatment ranged from a low of about 550 to a high of 4,350 lb/A.

High rainfall in May through August (Table 3) provided high yields in 1979, and yields of treatments

TABLE 5. INFLUENCE OF SUBSOILING AND DIKING TREATMENTS ON YIELD OF SORGHUM HYBRID (PIONEER 8501) IN 1979

		Distance Down Slope, In Feet									
		0-50		50-100		100-150		150-200		Average	
	Treatments	lb/acre	% of check	lb/acre	% of check	lb/acre	% of check	lb/acre	% of check	lb/acre	% of check
1&2	No treatment (check)	2939	68	4184	96	4973	114	5298	122	4353	100
3	Subsoiled[1]	4153	95	5237	120	5244	120	5111	117	4941	114
4	Diked[2]	4384	101	4855	112	4947	114	5256	121	4865	112
5	Subsoiled and diked	4898	113	4999	115	5255	121	5372	127	5136	119
	Average	3866c[3]	94	4696b	111	5084ab	117	5272a	122		

[1]Land was subsoiled 16 inches deep below the beds and furrows.

[2]Dikes were 50 ft apart (put in manually).

[3]Average values for distance down slope followed by same letter are not significantly different at 5% probability level.

Average yields of treatments 3, 4, and 5 were significantly higher yielding than check at 5% probability level.

ranged from 2,900 to almost 5,400 lb/A. The average yield increases, due to subsoiling and diking, were 14 and 12 percent, respectively. Even though the dikes were 50 ft apart the effects of location with respect to the slope on yields were highly significant. Visual observations and plant height measurements, as indicated in Table 9, showed a growth gradient between dikes. Plants close to the dikes on the upper side of the slope were 36 percent taller and appeared more productive than plants 25 and 50 ft from the dikes. These results indicated the need for shorter intervals between dikes and the need for determining plant response and moisture use with respect to the location down the slope. As shown in Table 5, the effect of distance down slope had a highly significant effect on sorghum yields. Yields for treatments either diked or subsoiled were from 1,214 to 1,959 lb/A higher than the check at the top of the slope, but there was essentially no difference among the treatments at the bottom of the slope. The average yield increase due to diking, subsoiling, and diking plus subsoiling ranged from 12 to 19 percent (Table 5).

Yields in 1980 were very low, ranging from 550 to almost 800 lb/A (Table 6). Because of the very low yields, sorghum was not harvested with respect to the distance down slope. Low rainfall and high evaporative conditions, as shown in Table 3, were responsible for the extremely low crop yields in 1980. However, as shown in Table 6, sorghum grown under diking produced about 250 lb/A more than the check treatment. Their response may have been due to a small increase in moisture captured and stored by diking.

Yields in 1981 (Table 7) ranged from a low of about 300 to a high of 2,550 lb/A. As shown in Figure 1, sorghum response to diking on the upper and middle section of the slope was dramatic. Diking, location with respect to slope, and the interaction of diking location with respect to slope significantly influenced yields. The average yield of the diked treatments was more than double that of the check.

TABLE 6. YIELDS OF GRAIN SORGHUM HYBRID (PIONEER 8501) UNDER DIFFERENT CULTURAL TREATMENTS OF SUBSOILING AND DIKING IN 1980

Treatments	lb/acre	% of check
1 No treatment (check)	547 b[4]	100
2 Diked[1]	747 ab	137
3 Subsoiled[2]	580 ab	106
4 Diked[3]	751 ab	138
5 Subsoiled and diked[3]	791 a	145

[1]Land was machine-diked 8 ft apart.

[2]Land was subsoiled 16 inches deep below furrow and beds in 1979.

[3]Land was machine-diked 4 ft apart.

[4]Average values for treatment followed by same letter are not significantly different at 5% probability level.

Average yield from diking was significantly higher yielding at 5% level of probability.

TABLE 7. INFLUENCE OF SUBSOILING AND DIKING ON SORGHUM HYBRID (PIONEER 8501) YIELDS AND % YIELDS WITH RESPECT TO CHECK IN 1981

	Distance Down Slope, In Feet							
	0-60		60-120		120-180		Average	
Tillage Treatments	lb/acre	% of check	lb/acre	% of check	lb/acre	% of check	lb/acre	% of check[1]
1 Check	478	46	950	92	1683	162	1038 b	100
2 ½ Diked	1440	139	1779	171	2358	227	1861 a	179
3 Subsoiled	313	30	528	51	2503	241	1116 b	108
4 Diked	1808	174	2301	222	2558	246	2240 a	216
5 Subsoiled and Diked	1940	187	2562	247	2237	216	2248 a	217
Average	1177c[2]	113	1603b	154	2230 a	215		

Tillage treatments and distance down slope significantly influenced yields at 1% probability level. Interaction of tillage treatments x distance down slope was significant at 5% probability level.

[1]The % of check refers to yield in lb/acre ÷ 1038 x 100.

[2]Average value for treatments and distance down slope followed by same letter are not significantly different at 5% probability level.

TABLE 8. AVERAGE YIELDS OF SORGHUM HYBRID (PIONEER 8501) GROWN UNDER DIFFERENT TILLAGE TREATMENTS FROM 1979-1981

	Years							
	1979		1980		1981		Average	
	lb/acre	% of check	lb/acre	% of check	lb/acre	% of check	lb/acre	% of check
Check	4353	100	547	100	1038	100	1979	100
Subsoiled	4941	114	580	106	1116	108	2212	112
½ Diked	—	—	—	—	1861	179	—	—
Diked	4865	112	751	138	2240	216	2619	132
Subsoiled and Diked	5136	119	791	145	2248	217	2725	138

TABLE 9. PLANT HEIGHT ON UPPER SIDE OF SLOPE AS INFLUENCED BY DISTANCE FROM DIKE IN AUGUST, 1979

Distance from dike ft.	Plant height inches	% of check[1]
0	46.5	136
25	42.1	123
50	36.0	105

[1]Average plant height of check treatment was 34.3 inches.

Diking every other row increased yields over the check by almost 80 percent. On the upper side of the slope, diking increased sorghum yields from an average of 396 to 1,874 lb/A or almost a five-fold increase in yield. A yield of 2,240 lb/A from the diked treatment instead of the 1,038 lb/A from the check could possibly be the difference between a profitable or an unprofitable cash crop for the Rolling Plains. The average yields and the percent increase in yield due to diking and subsoiling over the check are given for each year in Table 8. The average over the 3-year period is also shown. Diking and diking plus subsoiling increased sorghum yields by 32 and 38 percent, respectively. Subsoiling alone increased sorghum yield an average of 12 percent and most of that increase was in 1979 when the land was subsoiled on 20-inch intervals parallel with rows. The low response to subsoiling in 1980 and 1981 indicates that the residual effects of subsoiling were small. Studies presently underway indicate that compaction, which is partly rectified by subsoiling, is only one of the factors reducing water intake of soils. Other conditions, such as organic matter, plant residue, and soil moisture conditions at time of rainfall also influence the water intake of the soil and the amount of run-off during any significant rainfall. To ascertain the desirability of subsoiling, more research is needed.

In 1981 the influence of diking on sorghum yields was dramatic. Soil moisture measurements indicated that diking increased moisture storage on the upper slope by about 2 inches. This extra 2 inches of water, as shown in Figure 2, meant approximately 1,600 lb/A. Assuming the relationship between yield and water use holds between 4 and 8 inches, water uses of 4.5, 6, and 8 inches of water produced about 0, 1,200, and 2,780 lb/A in 1981 (Figure 2).

Yield response to available soil water is influenced by climatic or evaporative conditions. In 1977 the relationship between water use and sorghum yields at Munday indicated that more than 5.0 inches of water were needed before any grain was produced (5). As shown in Figure 3, in 1981 the relationship between sorghum yield and water use in inches per day by sorghum during the 30- to 60-day period was highly significant. Diking, as shown in Figure 4, increased the water use during this critical panicle development stage in upper and middle part of slope from about 0.06 inch per day to almost 0.10 inch per day. Many plants on the upper and middle part of the slope on check and subsoiled treatments (1 and 3, Table 2) which used only 0.06 inch per day failed to produce any grain. This difference in water use during the critical growth stage apparently resulted in sorghum yielding an average of 2,200 instead of about 400 lb/A.

The average water use in inches for 1979 and 1980 is shown in Table 10. In 1979 the average water use was measured about 75 ft down slope. The pounds of sorghum produced per inch of water was high, ranging from 350 to 424 (Table 10). In 1980, water use averaged about 7.0 inches and the sorghum produced per inch of water was extremely low, ranging from 80 to 110 lb/inch (Table 10). As shown in Table 11, 1981 water use ranged from 5.5 to 7.7 inches of water and production ranged, depending upon treatment and site with respect to slope, from 66 to 351 lb/inch of water. The average response by diked

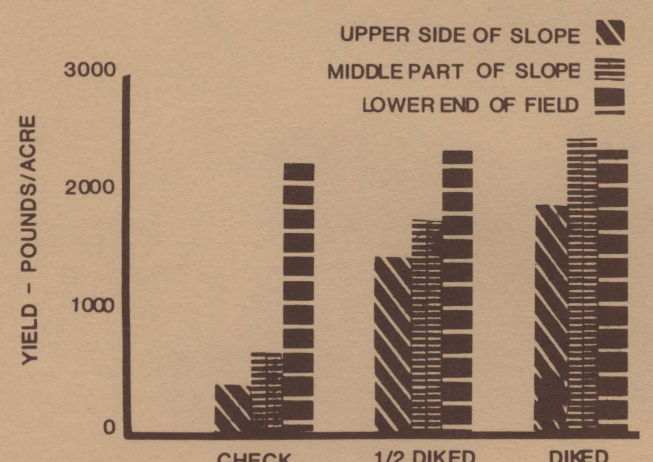

Figure 1. Bar graph showing the effects of slope and diking on grain sorghum yields in 1981.

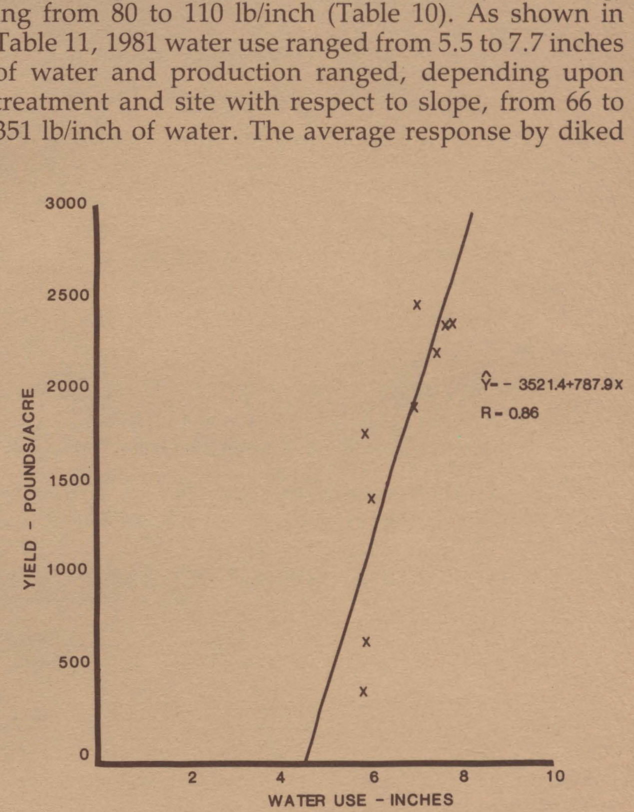

Figure 2. Relationship between yields of sorghum under different tillage treatments and moisture use in inches by sorghum in 1981.

TABLE 10. WATER USE AND GRAIN YIELD PER INCH OF WATER FOR VARIOUS TILLAGE TREATMENTS IN 1979 AND 1980

	1979		1980	
Treatments	Water use inches	Grain lb/in of H_2O	Water use inches	Grain lb/in of H_2O
Check	12.4	350	6.5	84
Subsoiled	12.5	395	7.3	80
Diked	12.7	382	7.3	103
Subsoiled and Diked	12.1	424	7.2	110
Average	12.4	388	7.1	94

treatment, 312 lb/inch of water, is almost identical to the average production per inch of water at Munday from 1976-1978 (5).

Yield Potential for Sorghum in the Rolling Plains

As shown in Figure 5, dryland sorghum yields from 1976-1981 were inversely related to water deficit in the range of 35 to almost 60 inches. This regression, which included data from Munday and Chillicothe, was highly significant. Estimates of water deficit for the months of May through September for the last 68 years were made, and frequencies of water deficits by 5-inch increments are shown in Table 12. About 90 percent of the time, the water deficit ranged from 35 to 55 inches. Years like 1980 with a deficit of about 58 inches occurred less than 5 percent of the time (Table 12). During very dry years such as 1980, diking probably would have little influence on yields. Diking also probably would have little effect during very wet years. However, in years such as 1981 which had very low rainfall during the growing season but significant rainfall before planting, diking can more than double grain sorghum yields (Table 7). Maximum yields with ideal climatic conditions and present varieties would probably range from 4,000 to 5,000 lb/A. Estimated yields in Table 12 based on water deficits over 68 years show that one could expect yields greater than 2,100 lb/A 69 percent of the time. Half of the time yields would range from 2,100 to 4,400 lb/A and 31 percent of the time yields would be less than 2,100 lb/A. These yields were estimated for grain sorghum grown with conventional tillage systems. Planting at the proper time plus diking and subsoiling, if needed, would increase the probability of producing yields near 3,000 lb/A.

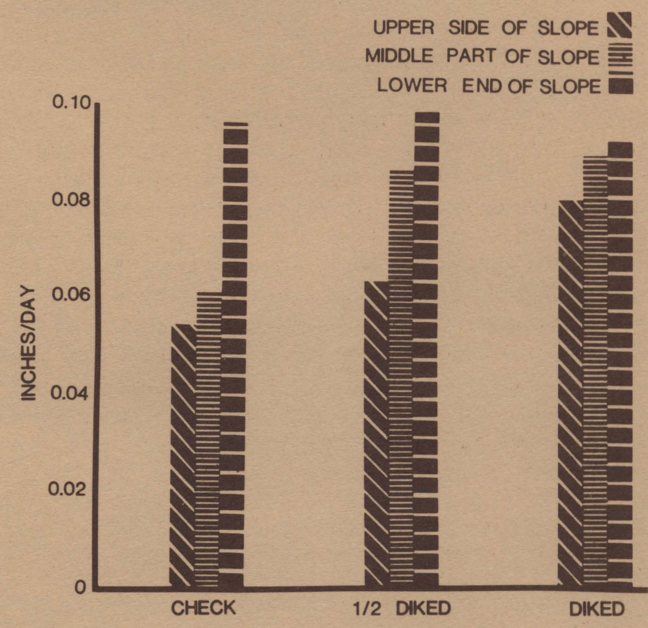

Figure 4. Bar graph showing effects of slope and diking on water use in inches/day during the 30- to 60-day period of growth for sorghum in 1981 at Chillicothe.

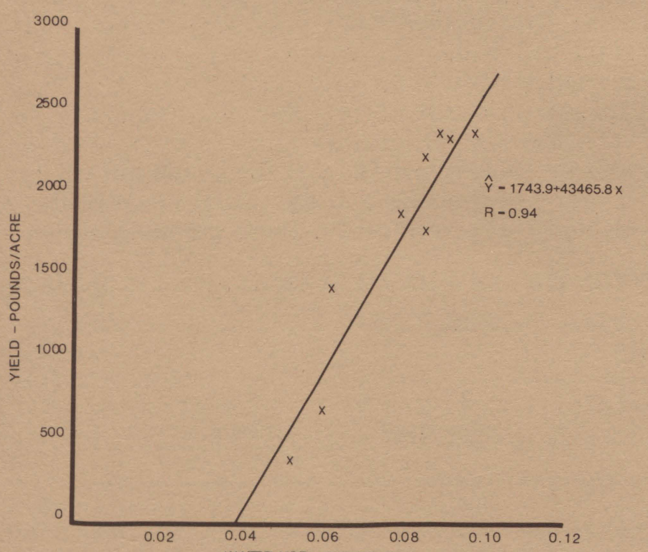

Figure 3. Relationship between yields of sorghum under different tillage treatments and moisture use in inches/day by sorghum during the 30- to 60-day period of plant development in 1981.

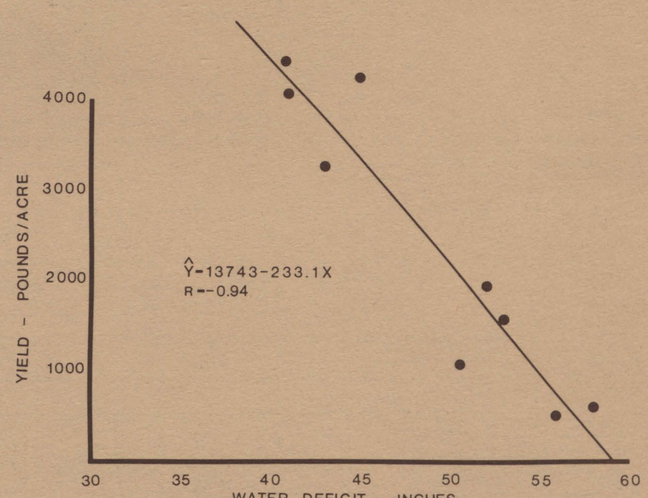

Figure 5. Relationship between water deficits and dryland sorghum yields from conventional tillage at Chillicothe and Munday from 1976 to 1981.

TABLE 11. WATER USE AND PRODUCTION OF GRAIN SORGHUM PER INCH OF WATER AS INFLUENCED BY DIKING AND DISTANCE DOWN SLOPE IN 1981

	Distance Down Slope, In Feet							
	0-60		60-120		120-180		Average	
Treatment	water use inches	lb/in of H_2O	water use inches	lb/in of H_2O	water use inches	lb/in of H_2O	water use inches	lb/in of H_2O
Check	5.5	66	5.9	113	7.5	298	6.3	159
½ Diked	6.0	240	5.9	303	7.7	307	6.5	283
Diked	6.9	273	7.1	351	7.5	312	7.2	312
Average	6.1	193	6.3	256	7.6	306		

Management Effects on Soil Properties

Effect of cropping systems on selected soil properties are shown in Tables 13, 14, and 15. The findings, though not conclusive, do show certain trends. The data in Table 13 indicate that soil from the wheat and sorghum cropping systems had significantly higher organic matter contents than soil from other systems. Plant residues decompose rapidly under the climatic conditions of the Rolling Plains. This is indicated by the generally low soil organic matter content and by the organic matter contents of the 6- to 12- and 12- to 24-inch soil depths which are almost as high and sometimes higher than the organic matter of the soil surface. The data in Table 14 indicate that the bulk densities of the Miles fine sandy loam soil tend to be high, but the sorghum residues significantly reduced the bulk density of the surface soil. These data show that sorghum tends to increase organic matter in the soil surface more than the other cropping systems. Peerlkamp (9) visualized soil structure as a function of organic matter. He suggested that soil structure deteriorates rapidly unless the organic matter is replenished periodically. A modified diagram from Peerlkamp (9) showing an idealistic relationship between soil structure, organic matter, and time is shown in Figure 6. Many soils in the Rolling Plains and Texas (3) have poor structural stability because of low organic matter.

The effects of cropping systems, depth, and time of sampling on K_s of a Miles fine sandy loam soil at Chillicothe are shown in Table 15. In the fall of 1980, samples from the surface soil of cropping systems involving sorghum and cotton had significantly higher K_s than soils under cropping systems involving wheat. In the spring of 1981, all the soils including the land under sorghum had low saturated K_s (Table 15). The surface soil following wheat and wheat-guar crops had higher K_s than cotton and sorghum cropping systems in the spring of 1981. In the fall of 1981, surface soil following sorghum had higher K_s than the other cropping systems. Data in Table 15 also indicate reduced permeability of the 9- to 12-inch soil depth in all cropping systems and at all sampling dates. The effects of the previous sorghum crop on K_s in the spring and the effect of previous wheat crop in the fall suggest that sorghum and wheat residues decompose rapidly during the fallow period of the year. The effect of plant residues on permeability of soils probably depends upon the amount of residue returned to the land and the management of these residues. The residues in these cropping systems

TABLE 12. SUMMARY OF WATER DEFICIT FOR MONTHS MAY THROUGH SEPTEMBER FROM 1914-1981 AT CHILLICOTHE, TEXAS

Water Deficits inches [1]	No. of Years	Frequency %	Estimated Yield Range lb/acre
30-35	4	5.9	5600-6700
35-40	10	14.7	4400-5600
40-45	16	23.5	3300-4400
45-50	17	25.0	2100-3300
50-55	18	26.5	900-2100
55-60	3	4.4	0-900

[1]Water Deficit (inches) = Pan evaporation from Class A pan (inches) for months of May through September minus rainfall (inches) for months of May through September.

TABLE 13. INFLUENCE OF CROPPING SYSTEMS ON ORGANIC MATTER CONTENT OF A MILES FINE SANDY LOAM SOIL IN DECEMBER, 1980

	Treatment					
Depth inches	Continuous wheat	Continuous cotton	Continuous sorghum	Cotton-guar	Wheat-guar	Average
	%					
0-6	0.52	0.34	0.63	0.41	0.47	0.47 a*
6-12	0.49	0.38	0.47	0.41	0.40	0.43 b
12-24	0.51	0.30	0.45	0.47	0.47	0.46 a
Average	0.51 a*	0.34 b	0.51 a	0.43 b	0.44 ab	

*Average values for cropping systems and depth followed by same letter are not significantly different at 5% probability level.
Interaction of depth x treatment was also significant.

studies were usually mixed with the surface soil. The precise effect of minimum or reduced tillage on properties of Rolling Plains soils are presently under investigation at Munday, Texas. It should be pointed out that the low K_s value of sorghum and cotton cropping systems in the spring of 1981 may be indicative of the very poor growth and production of these crops in 1980.

The amount of air dry residue produced by two grain sorghum varieties producing 2,000 to 8,000 lb of grain/A in 1981 are shown in Figure 7. The amount of residue produced by sorghum yielding less than 2,000 lb of grain/A needs further study. In the range shown in Figure 7 about 1 lb of vegetative plant part was needed to produce 1 lb of grain. Grain varieties may influence this relationship. Data indicate that sorghum production would return a significant amount of residue to the land and have important long-term effects on soil productivity.

The effects of residue and antecedent moisture on K_s of the Miles and Abilene surface soils after several wetting and drying cycles are shown in Figures 8 and 9, respectively. It is obvious that plant

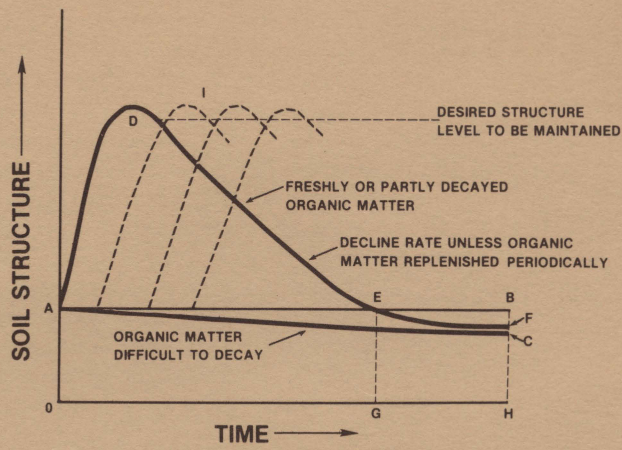

Figure 6. Change of soil structure with time after adding organic matter at time 0. Structure will deteriorate rapidly unless the organic matter is replenished periodically through the use of well-planned cropping systems. Modified from Peerlkamp (9).

TABLE 14. INFLUENCE OF CROPPING SYSTEMS ON BULK DENSITY AT DIFFERENT DEPTHS OF A MILES FINE SANDY LOAM IN DECEMBER, 1980

Depth inches	Continuous wheat	Continuous cotton	Continuous sorghum	Cotton-guar	Wheat-guar	Average
			g/cm^3			
0-6	1.45	1.42	1.28	1.45	1.38	1.39 b*
6-12	1.48	1.42	1.52	1.59	1.51	1.50 a
12-24	1.49	1.54	1.51	1.47	1.40	1.48 a
Average	1.47	1.46	1.44	1.50	1.43	

*Average values for depth followed by same letter are not significantly different at 5% probability level. Effects of depth and interaction of treatment x depth were significantly different at 5% probability level.

TABLE 15. INFLUENCE OF CROPPING SYSTEMS, DEPTH, AND TIME OF SAMPLING ON SATURATED HYDRAULIC CONDUCTIVITIES OF A MILES FINE SANDY LOAM AT CHILLICOTHE, TEXAS

	Dates of Sampling[1]									
	12/4/80[2]			6/24/81[3]			11/12/81[4]			
	Depth, inches									
	0-3	9-12	Average	0-3	9-12	Average	0-3	9-12	Average	Overall Average
	K_s, inches/hour									
Continuous wheat	0.31	0.44	0.38 c	0.58	0.10	0.34	1.70	0.72	1.21	0.64
Continuous cotton	1.35	0.45	0.90 b	0.31	0.24	0.28	1.65	0.51	1.08	0.75
Continuous sorghum	1.98	0.33	1.16 a	0.18	0.29	0.24	3.18	0.69	1.94	1.11
Cotton-guar	1.89	0.35	1.12 ab	0.13	0.10	0.12	2.85	0.30	1.58	0.94
Wheat-guar	0.57	0.35	0.46 c	0.79	0.09	0.44	1.80	0.28	1.04	0.65
Averages	1.22	0.38		0.40	0.16		2.24	0.50		
	a	b		a	b		a	b		

[1]Significant differences are shown within each year.

[2]Average value for cropping systems and depth followed by same letter are not significantly different at 5% probability level. Averages of depth and depth x treatment interaction were significant at 1% probability level.

[3]Average effects of depth and interaction of depth x treatment were significant at 5% and 1% probability levels, respectively. Average effects of wheat and wheat-guar were significantly higher at 10% probability level.

[4]Average effects of depth and depth x treatment were significantly higher at 1% and 5% probability levels, respectively. Effect of sorghum was significantly higher than effects of other cropping systems at 5% probability level.

residue or organic matter, antecedent moisture (4), and clay content of soils significantly influence the ability of these soils to take in water. Rains that fall on weakly structured wet Rolling Plains soils often run off the land because of low saturated conductivities of the soils. Drying or suction may make the organic molecules more effective in stabilizing microaggregates. Foster (2) reported that small quantities of microbial polysaccharides are able to stabilize clay aggregates. Sands *et al.* (11) reported that organic matter and management were important in maintaining favorable soil structure in deep, sandy soils.

Compaction is another important factor. On many soils, including the Miles fine sandy loam soil, hardpans or compacted layers occur 10 to 15 inches from the soil surface (Figure 10). This soil has a hardpan layer at about the 10-inch depth. The compacted layer has 25 to 30 percent clay and often has sufficient strength as measured with a penetrometer to almost stop root growth at optimal moisture conditions.

With removal of a small amount of moisture through evaporation or use by plants from these layers, soil strength of these layers as measured with a penetrometer, are 50-100 atmosphere rather than 20-25 atmosphere. Under field moisture conditions plants cannot penetrate these layers. The water storage reservoir of these soils is essentially only 10 inches deep. This often means poor root growth, low yields, and severe runoff and erosion. Subsoiling, as shown in Figure 10, is needed to increase the water storage reservoir in such soils.

RECOMMENDATIONS AND CONCLUSIONS

Profitable dryland production of grain sorghum seems feasible for much of the Rolling Plains of Texas. An average of 3,000 lb of grain/A should be produced when proper planting date, variety, furrow diking, and subsoiling are used. In order to achieve this yield level certain operations and conditions which are outlined below would be required.

Field and laboratory studies indicate that for many soils in the Rolling Plains, furrow diking is a practical means of stopping the occurrence of significant runoff and erosion. Furrow dikes at 4- to 8-feet apart should be put in place in early spring and again after stand establishment. This production strategy is aimed at storing and harvesting rainfall from the two significant rainfall periods — April through mid-June and September to October. The furrow dikes should be capable of retaining 2 or 3 inches of rain without runoff. The lay and slope of some fields may be such that furrow dikes alone could not effectively prevent runoff and severe erosion.

It is recommended that a medium-maturing hybrid be planted between June 10 and June 20. As soon as stands are established and early cultivation, including fertilization, is completed, dikes should be put back in place. Preplant and postplant herbicide applications have been used with reasonable success. Some years it may be necessary to cultivate to control

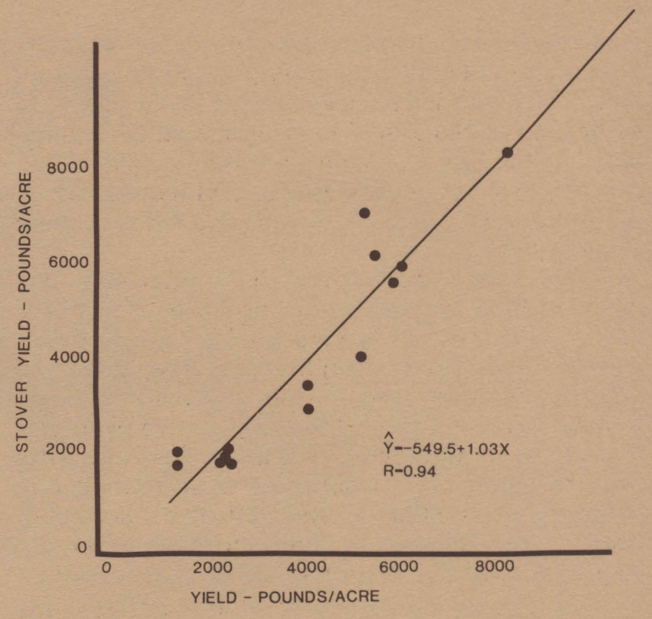

Figure 7. Relationship between grain yield and air dry stover yields at Chillicothe in 1981.

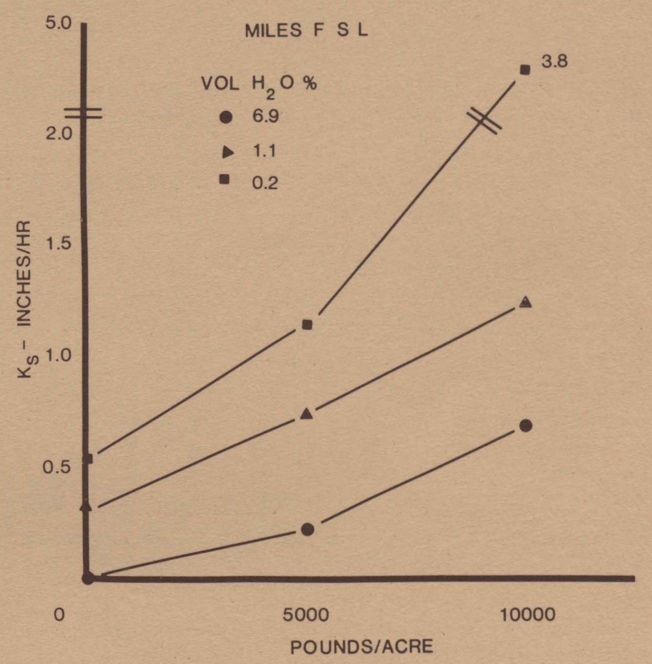

Figure 8. Effects of antecedent percent moisture and plant residues on K_s of a Miles fine sandy loam soil.

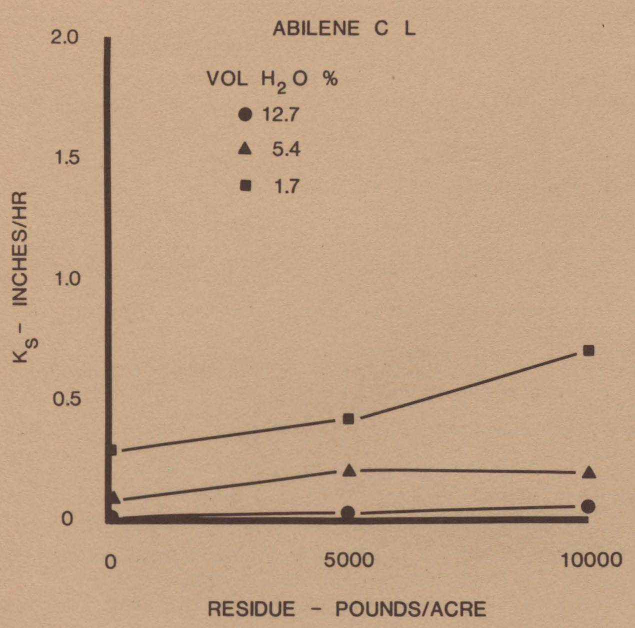

Figure 9. Influence of antecedent percent moisture and plant residue on K_s of an Abilene clay loam.

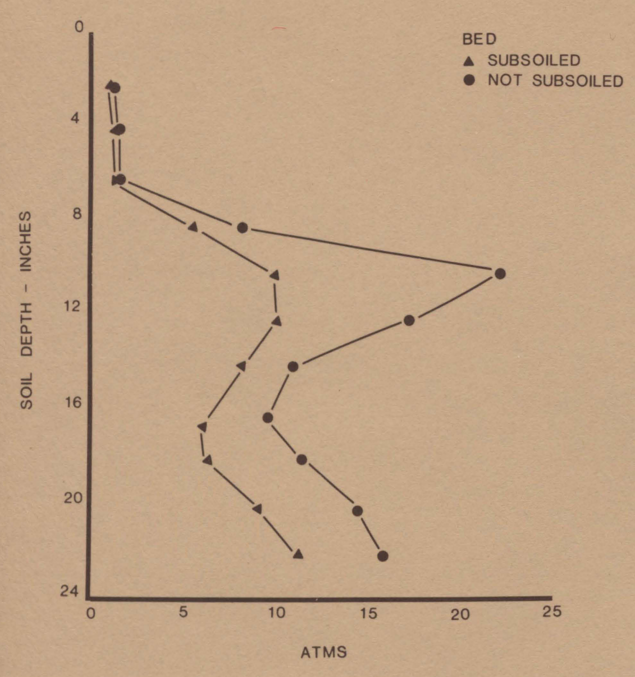

Figure 10. The effect of subsoiling on soil strength in atmospheres of top 24 inches of a Miles fine sandy loam.

weeds. Under these conditions it may require one or two field operations for control of weeds and replacement of dikes.

After harvesting in some years it may be possible to use dikes already in place to catch water for the next crop. In the event of an earlier planting or harvesting, consideration should be given to killing or plowing out stalks. If this is not done, considerable moisture may be extracted by the remaining green stubble. Obviously, this moisture could be used by the next crop. The stubble also may be used for grazing, and if yields are quite low, the entire crop might be grazed out.

In summary, sorghum returns more residue to the land than present dryland cropping systems. This is certainly true of the main cash crop, cotton (12). Use of dikes would not only increase grain but stover yields as well. Studies have shown that the permeability of many soils as measured by saturated hydraulic conductivity is a function of a number of factors including the amount of residue returned to the soil by crops. Return of sorghum residues should favorably influence the yields of subsequent crops. The precise amount or degree of increased productivity of the land is not yet known. Minimum tillage might make the effectiveness of sorghum as a residue crop even greater than suggested by the soils data. Further studies are presently underway to clarify the benefits and problems, if any, of minimum or reduced tillage. Sorghum production in the long run probably will mean significantly higher yields of other crops such as wheat and cotton.

It is the purpose of this publication, using past climatic data and recent yield records, to provide an estimate of potential sorghum yields for the Rolling Plains. It should be possible from these parameters to estimate the economic feasibility of sorghum production systems. These data emphasize that runoff often can be prevented and additional water captured for crop production by furrow diking and subsoiling where required. Plant residues can play important roles in soil productivity and in the production of crops such as sorghum, cotton, and wheat in the Rolling Plains of Texas.

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